DISTRIBUTION CURVES OF ARC LAMPS AND INDIRECT LIGHTING UNITS

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ARMOUR INSTITUTE OF TECHNOLOGY

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Determination of Distribution Curves of Arc Lamps and Indirect Lighting Units

A THESIS

PRESENTED BY

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DETERMINATION OF DISTRIBUTION CURVES OF ARC LAMPS AND INDIRECT LIGHTING UNITS.

The work of this thesis embodies two commercial tests supplemented by some survey work on an indirect lighting system. On the two commercial tests the writers worked in conjunction with Professors Freeman, Moreton and Marsh.

The object of the first test was to obtain the distribution curve of the arc used in the headlight of the Chicago, Burlington & Quincy Railroad. Two curves were obtained, one with a carbon-carbon arc and one with a copper-carbon arc.

The object of the second test was to obtain the distribution curves of the various sizes of Indirect "Alexalite" Diffusers sold by the Central Electric Company.

For the third part of this work a 500 watt spherical Mazda unit with a 22" Diffuser was installed in the Electricity Lecture Room.
A survey was run and a comparison made between indirect and direct lighting systems.

DESCRIPTION OF THE APPARATUS.

The apparatus consisted of a "Twin Mirror" photometer stand,a wooden casing for the stand, photometer bench,photometer head,suitable light screens,regulating rheostats,etc,.

The stand is made of a strong,but light composite metal. It has two revolving arms,each carrying a mirror about 2 feet square. Balance weights are placed on the ends of the arms opposite the mirrors,thus enabling them to be placed at any angle. The mirrors are attached to the arms by double pivots so that they may be revolved in either a horizontal or vertical direction and can be placed in any desired position. The shaft upon which the arms revolve is drilled longitudinally through its center. The opening is about 1/32" in diamater. By sighting through this opening,one is enabled to line up the photometer head,bench and lamp on a line midway between the mirrors. A pointer is attached to the end of each arm and travels over a scale of degrees marked on the black background of the casing. By revolving the mirrors,readings may be taken

of the candle power in all directions around the source.

In order to eliminate,as far as possible, the effect of stray light,the mirror is placed in a wooden casing enclosed on five sides,the opening on the sixth side being allowed for the light to pass out to the photometer head,after being reflected by the mirrors. The interior of the casing is painted a rough jet black and is very nearly non-reflecting. A black wooden screen about 2 feet square is hung in front of the opening so as to preclude the possibility of any light from the source going directly to the photometer head. A skeleton diagram of the arrangement of the apparatus is shown in plates # 1 and # 2.

During the tests two different Photometers were used,"The Flicker" and "The Equality-of-Brightness". The photometer head was fastened rigidly to the bench and was surrounded by light screens. A sectored disc was used to increase the range of the apparatus. The standard lamp,was mounted on a movable carriage,its position being shifted by means of an

endless cord and pulley arrangement.

The rheostats used were of the carbon plate and manganin wire types. In all cases possible the regular Weston standard laboratory instruments were used. These were duly calibrated and corrections made.

The source of power used for the standard lamp was the large battery on the second floor. This gave a very steady voltage ,thus eliminating the possibility of errors due to fluctuation in voltage.

DISTRIBUTION CURVE OF HEADLIGHT ARC.

In commercial use the power for the headlight is obtained from a turbine driven compound generator mounted on the top of the boiler behind the smoke stack. Because of the lack of facilities for the use of steam,the generator was belted to a shunt motor during the test. The speed of the generator was checked at intervals of one minute.

The arc was mounted on a stand and accurately located on the photometric axis midway between the mirrors. The height of the arc was adjusted

so as to fall on the center revolution of the mirrors. The proper voltmeter,ammeter and wattmeter connections were made to the arc.

During this test the photometer bench was placed in a room adjacent to the one in which the arc was located. Suitable light screens were hung in front of the bench and in the doorway of the room,thus shutting out nearly all but those rays coming from the mirrors. Due to the vast difference in color between the light from the arc and the light from the standard incandescent lamp,"The Flicker" Photometer was chosen for this test. Because of the peculiar arrangement of the comparison screen in this photometer, the angle of incidence of the light from the mirrors varies with the angular position of the mirrors. In order to eliminate the error from this arrangement,a diffusing screen was placed in front of the comparison screen of the photometer head.

Before starting on the test proper,it was necessary to calibrate the complete apparatus. For this purpose one of the mirrors was removed from the stand and brought up close to

the photometer head. Then by means of a second standard lamp, the mirror being placed at the same angle as it was in the stand, the absorption due to the mirror and the diffusing screen was determined.

Because of the poor regulation of the arc the power consumed by it varied somewhat widely and rapidly. It was therefore necessary to determine the average wattage consumed by the lamp. Readings were taken at intervals of 15 seconds, the speed of the generator being held normal and the average power thus deduced.

In order to secure consistent results, it was found necessary to take photometric balances, only at times when the wattmeter needle indicated within a few watts of average power.

Since the wattmeter was placed near the arc, it was necessary to wire a buzzer and push button circuit from the wattmeter into the room where the balance was being taken. One observer was stationed at the wattmeter and pressed the button whenever the indication on the wattmeter was such as to permit a reading to be taken. Readings of the candle power were taken

every 10 degrees around the arc. Since two mirrors were used, one on each side, errors due to the shifting of the arc around the electrodes were reduced. It was, of course, necessary in calculating to divide the results by two. About fourteen settings of the standard lamp were taken for each position of the mirror. These settings were made only during normal power consumption as indicated on the wattmeter. It was necessary to use several different size standards because of the large range in candle power.

Because of the fact that the back of the casing reflected some light, there was found to be some illumination on the photometer screen, even when the mirrors were covered with black velvet. The error due to this stray light was eliminated by placing a small unit on the same side of the screen as the standard lamp. By means of a suitable reflecting surface, enough of the flux from the small lamp was thrown on the standard side of the photometer screen to exactly balance the stray light coming

from the back of casing and walls.

Values of candle power in the various directions around the arc were laid out on polar coordinates. The smooth average distribution curves were drawn through these points. From this curve the values of the candle power every 5 degrees around the arc were read off.

Using these values,the mean upper henispherical candle power,the mean lower hemispherical candle power and the mean spherical candle power were calculated by means of the "Set of Constants" method as described in " Light,Photometry and Illumination" by Professor W.E.Barrows.

Results were obtained on both carbon-carbon arc and copper-carbon arc. Results and curves are shown in the adjacent data.

DISTRIBUTION CURVES OF INDIRECT ALEXALITE REFLECTORS.

Before starting on this test, it was necessary to have two high candle power standards. For this purpose 2-150 watt Tungsten lamps were chosen. The lamps were thoroughly seasoned for a period of 200 hours so as to cause their candle power to assume a practically constant value. Preliminary measurements at periods of 20 hours each were made in order to see if the candle power had become constant. The lamps were then placed on the bench and calibrated against two secondary carbon standards, which had been previously measured at the Bureau of Standards.

Because of the color difference between the Tungsten and carbon lamps the Flicker Photometer was used. Readings were taken every five degrees in a horizontal plane around the lamp. A set of ten readings for every point was taken by each of the three observers in order to eliminate, as far as possible, personal error.

The instruments used were checked against standard instruments just before the test. Voltage and current were accurately adjusted before each set of readings. Storage Batteries were used as a source of power.

After the standards had been calibrated measurements were started on the reflectors. The reflecting units were suspended in between the mirrors. The bowl was hung so as to make its edges level. The complete unit was then adjusted until the center of the lamp fell on the photometric axis,and the center of the filament was at the center of revolution of the mirrors. The photometer bench was then moved up to within about 12 feet of the casing. The mirrors were adjusted until the eye of an observer at the photometer screen could clearly see the entire image of the reflector for all angular positions of the mirrors. This was done in order to make sure that all light from the unit was reflected toward the photmeter regardless of the position of the arms.

The "Equality-of-Brightness"Photometer was used in this test because the lights were of practically the same color. Stray light was balanced in the same manner as described in the previous test. The stray light balances were in each case checked by two or three observers.

The method used in this test was different than that used in the first test,in this case a comparison lamp being used. For this purpose a small spherical Mazda automobile headlight lamp was chosen. The filament of this lamp is wound in a conical form of very small dimensions. Since these lamps are intended for use in parabolic reflectors their light is made practically a point source. This lamp was thoroughly seasoned,but not calibrated,since it was not necessary to know its candle power value in order to calculate results.

Readings were taken at intervals of 5 and 10 degrees from the horizontal to the vertical with the reflector between the mirrors,and the comparison lamp on the photometer bench.
For each point a set of ten readings was taken by each of two observers and the averages used

in calculations.

The reflecting unit was then removed and one of the 150 watt previously standardized units was put in its place. Readings were then taken with the standard between the mirrors and the comparison lamp on the bench,the arms being horizontal. Readings were checked by two observers and were taken before and after the run on each of the reflectors. In operating the comparison lamp, balances were secured alternately from the right and left so as to give good average results.

Most of the instruments used were the regular Weston laboratory standards. Those,which were not,were carefully calibrated. Current and voltage readings were taken at short intervals so as to hold all conditions steady.

To increase the range of the apparatus a sectored disc was used first on one side of the head and later on the other side of the head. It was not permissible to use the sectored disc in the first test because of the selection of the Flicker photometer as a basis of comparison. The disc was turned at a fairly high speed by means of a small motor directly connected.

The constant for the sectored disc used was 5.95.

Five different curves were determined, two with the 15" reflector using 150 and 100 watt lamps and three with the 22" reflector using a 500, 400 and 250 watt lamp.

After disposing of the distribution curves of the reflectors a determination of the mean horizontal candle power of each of the lamps was made without its reflector. From this, the distribution curve, mean hemispherical candle power and flux in lumens can be determined. In case it ever becomes necessary to check the results, the lamp in the reflector must be operated so as to give the same horizontal candle power as was obtained in these tests. By figuring the output in lumens from the distribution curve of the reflector its efficiency may be determined.

Derivation of the equation for the calculation of results by the comparison lamp method is shown below:-

Let

Ref.c.p. = candle power from the reflector.

Sta.c.p. = horizontal candle power of standard.

Let

Com. c.p. = horizontal candle power of comparison lamp.

d° = the distance from the point between the mirrors to the photometer head, by way of the mirrors.

d' = the distance from the balance point of the comparison lamp to the photometer head when the reflector is between the mirrors.

d'' = the distance from the balance point of the comparison lamp to the photometer head when the 150 watt standard is between the mirrors.

With reflector between the mirrors and comparison lamp on the bench, a balance having been secured the equation is:-

$$\frac{\text{Ref.c.p.}}{\text{Com.c.p.}} = \frac{(d^\circ)^2}{(d')^2} \qquad (1)$$

With standard lamp between the mirrors and

the comparison lamp on the bench, a balance having been secured the equation is:-

$$\frac{\text{Sta.c.p.}}{\text{Com.c.p.}} = \frac{(d^{\circ})^2}{(d'')^2} \qquad (\ 2\ )$$

Dividing equation (1(by equation (2) we have:-

$$\frac{\text{Ref.c.p.}}{\text{Sta.c.p.}} = \frac{(d'')^2}{(d')^2}$$

Transposing, we have, as a working equation:-

$$\text{Ref.c.p.} = \frac{(d'')^2}{(d')^2} \times \text{Sta.c.p.}$$

HORIZONTAL ILLUMINATION SURVEY.

The object of this test was to make a survey of a room lighted by a 500 watt spherical Mazda lamp with a 22" Alexalite reflector. Measurements were taken for a few points using the bare lamp alone.

The room chosen for the test was the Electricity Lecture Room on the second floor of the main building. The floor of the room is laid out in one meter squares and convenient sockets are located on the wall by means of which ammeter and voltmeter readings may be taken for the lighting unit. The ceiling of the room is calcimined a cream white. The walls are colored a dark tan having blackboards around three sides and windows on the fourth. During this test the windows were covered by double shades of a light green color. The dimensions of the room are as follows:-

Height 14' 6" (4.38 meters)
Width 23' 0" (7.00 meters)
Length 27' 7" (8.40 meters)

During the test the line voltage fluc at-ed considerably so that all readings had to be later corrected to a 112 volt basis.

The photometer used was the ordinary Sharp & Millar portable type. This was calibrated against a 16 c.p.secondary carbon standard before the test.

On the first run a working plane 31" above the floor was used and survey stations were located as shown in the accompanying plan. The survey was made in the Northeast quarter of the room only. Dry cells were used as a source of power for the photometer lamp.

The results including foot candle intensities,average intensity,effective flux and effective lumens per watt are given in the data.

On the second run only nine stations were taken,the illumination being furnished by a bare lamp only. From the results shown a foot candle gradient line was drawn and gives a comparison between indirect and bare lamp systems of lighting. As shown by the curves,the indirect system gives a more uniform intensity than the bare lamp system.

In the third test the indirect system was used,the working plane being varied in height. Observations were taken directly under the center of the reflector and at a point 10" from the edge of the reflector. The intensity increased as the working plane was raised toward the reflector and at a point about three feet beneath the reflector the intensity reached a value of 15 foot candles.

During all tests it was found that the intensity directly under the reflector was always greater than at any other point in the room. At a glance it would appear that there should be somewhat of a shadow beneath the opaque reflector and the writers are not, at present,prepared to state definitely the reason for the occurrence of the highest intensity directly underneath the center of the reflector.

Arrangement of Twin Mirror Photometer.

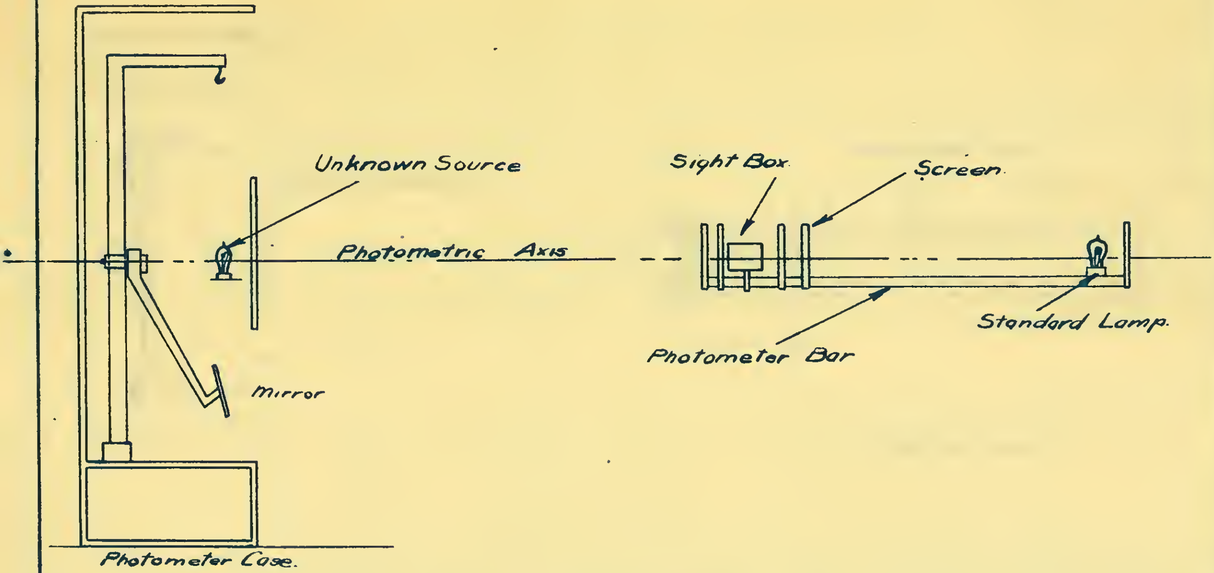


Fig. 1. Side Elevation.

Arrangement of Twin Mirror Photometer.

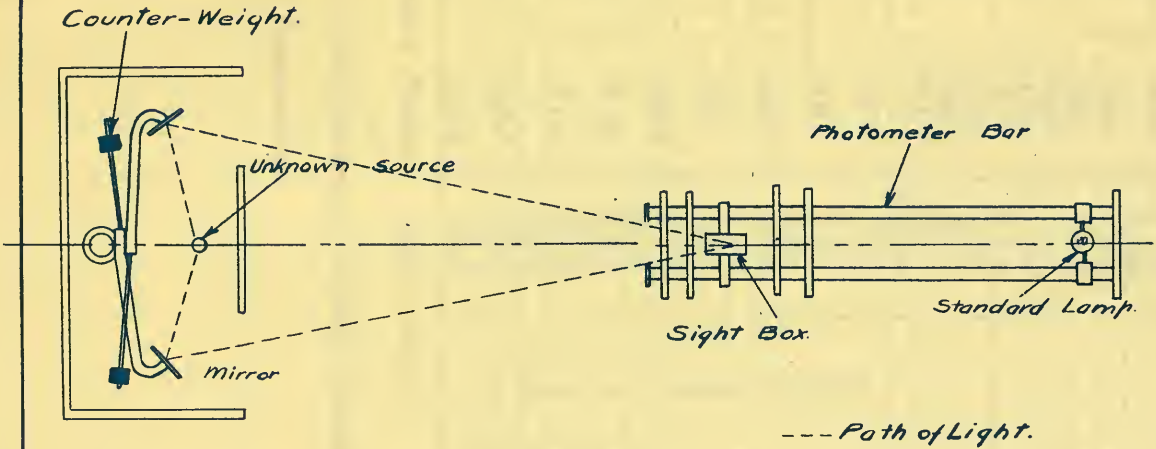


Fig. 2. Plan View.

Data and Results.
Test of Carbon Carbon Arc.

Degrees from Vertical (below)	Degrees from Horizontal.	Candle Power.	Candle Power from Curve.	Candle Power Constant.	Component M.H.S.C.P.	Average Watts.
0	90			.000952		
5				.007603		
10	80			.015149		
15				.022579		
20	70	250	250	.029837	7.46	1032
25		700	700	.036869	25.81	"
30	60	1480	1480	.043620	64.56	"
35		1825	1825	.050038	91.25	"
40	50	2105	2060	.056076	115.57	"
45		2066	2100	.061687	139.55	"
50	40	2096	2080	.066829	139.00	"
55		1960	1970	.071461	140.78	"
60	30	1860	1860	.075551	140.52	"
65			1700	.079066	134.47	"
70	20	1530	1530	.081977	105.46	"
75			1284	.084266	108.24	"
80	10	1170	1170	.085914	100.62	"
85			1048	.086901	80.70	"
90	0	950	950	.087238	82.88	"
95			880	.086901	76.47	"
100	10	831	831	.085914	73.47	"
105			774	.084266	65.25	"
110	20	732	732	.081977	60.02	"
115			660	.079066	52.14	"
120	30	570	570	.075551	43.06	"
125			478	.071461	34.18	"
130	40	400	400	.066829	26.72	"
135			280	.061687	17.28	"
140	50	170	170	.056076	9.54	"
145			132	.050038	6.60	"
150	60	105	105	.043620	4.58	"
155			54	.036869	1.99	"

Maximum Candle Power (from curve)	2100 at 45°
Horizontal " "	950
Lower Mean Hemispherical Candle Power	1435
Upper " " " "	512
" Spherical " "	974

RESULTS

"400 watt" Lamp with 22" Reflector

Degrees Above Horizontal.	Candle Power
0	11
10	205
20	385
30	450
40	480
50	491
60	450
70	420
80	415
90	410

Input = 381 watts at 110 volts.
Comparison Lamp - Headlight Mazda.
M. H. C. P. = 284.

"500 watt" Lamp with 22" Reflector.

Degrees Above Horizontal	Candle Power
0	10
10	193
20	488
30	610
40	662
50	695
60	682
70	660
80	682
90	680

Input = 470 watts at 110 volts.
Comparison Lamp - Headlight Mazda.
M. H. C. P = 415

RESULTS

"100 watt" Lamp with 15" Reflector.

Degrees Above Horizontal.	Candle-Power
0	22
10	66
20	83
30	88
40	93
50	94
60	88
70	69
80	71
90	79

Input = 94 watts at 112 volts.
Comparison Lamp – Headlight mazda.
M. H. C. P. = 69

"150 watt" Lamp with 15" Reflector.

Degrees Above Horizontal.	Candle-Power
0	12
10	71
20	131
30	154
40	163
50	167
60	164
70	136
80	112
90	137

Input = 138 watts at 110 volts.
Comparison Lamp – Headlight Mazda.
M. H. C. P = 112

RESULTS

"250 watt" Lamp with 15" Reflector.

Degrees Above Horizontal.	Candle-Power
0	12
10	125
20	245
30	299
40	324
50	322
60	295
70	248
80	235
90	230

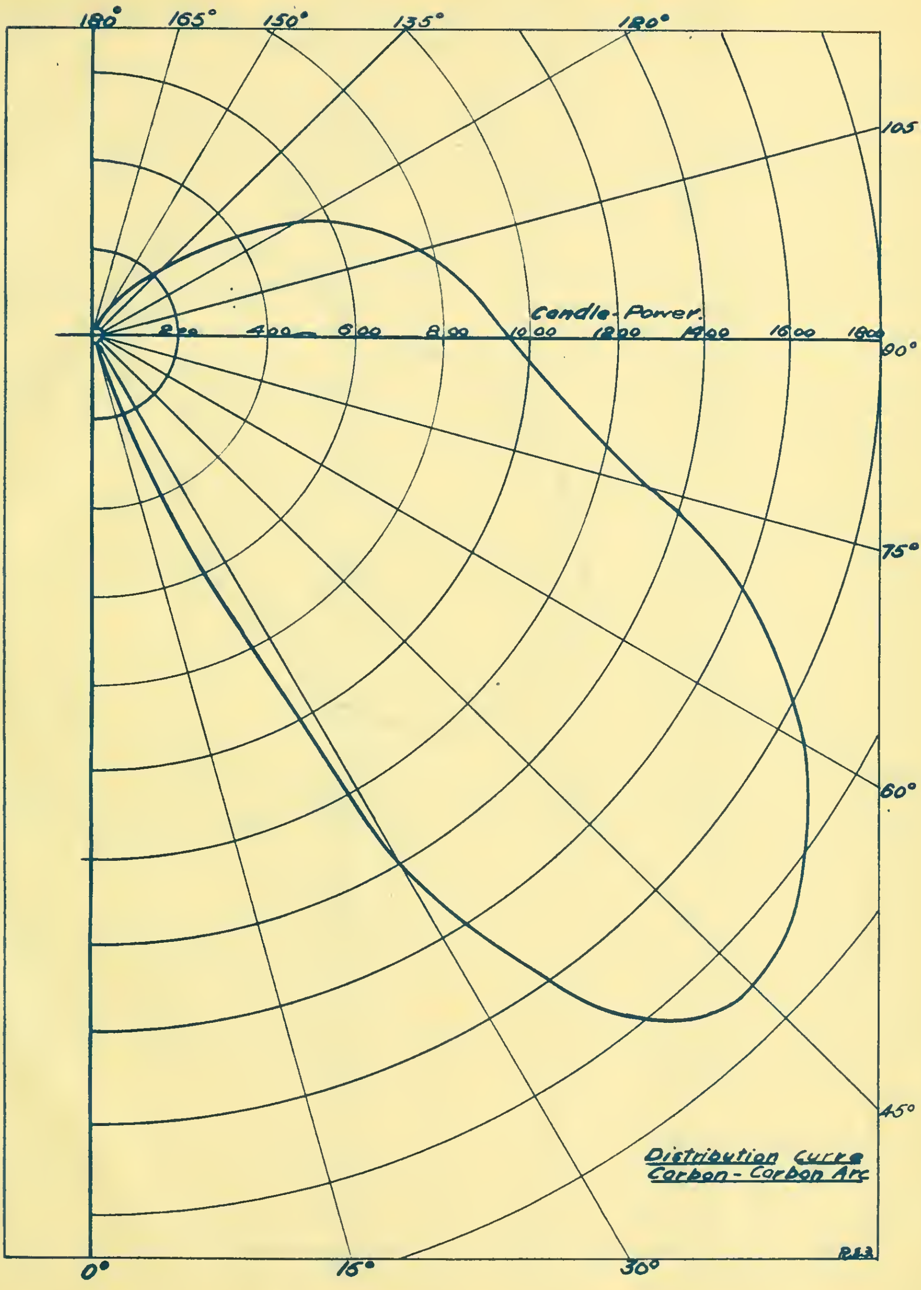
Input = 249 watts at 110 volts
Comparison Lamp – Headlight Mazda.
M. H. C. P. = 206.

NOTES

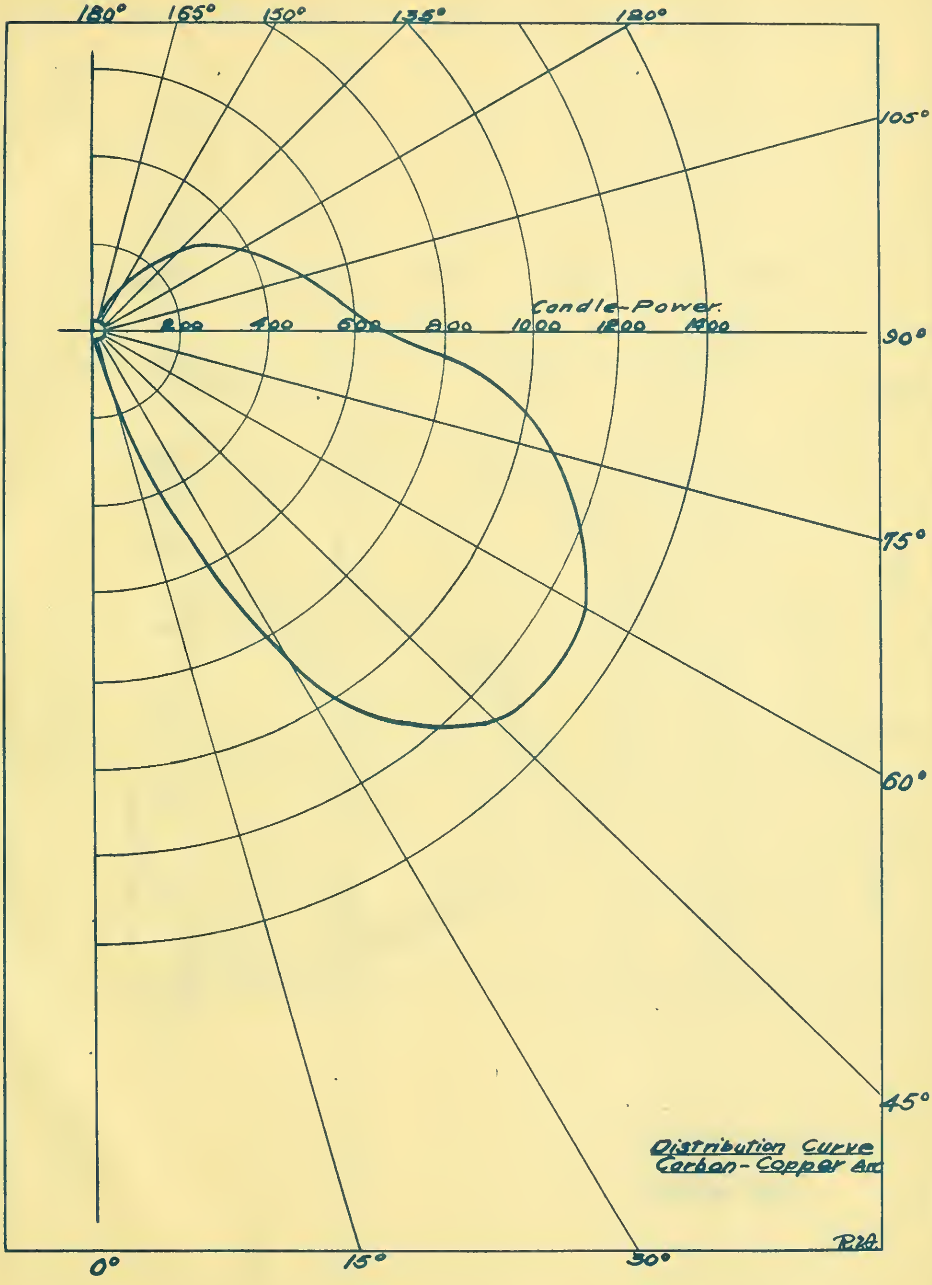
1. The sectored disk, multiplies or divides the apparent candle-power by 5.95.

2. The candle-power of the 150 watt lamp, called #1, used as a working standard = 119.

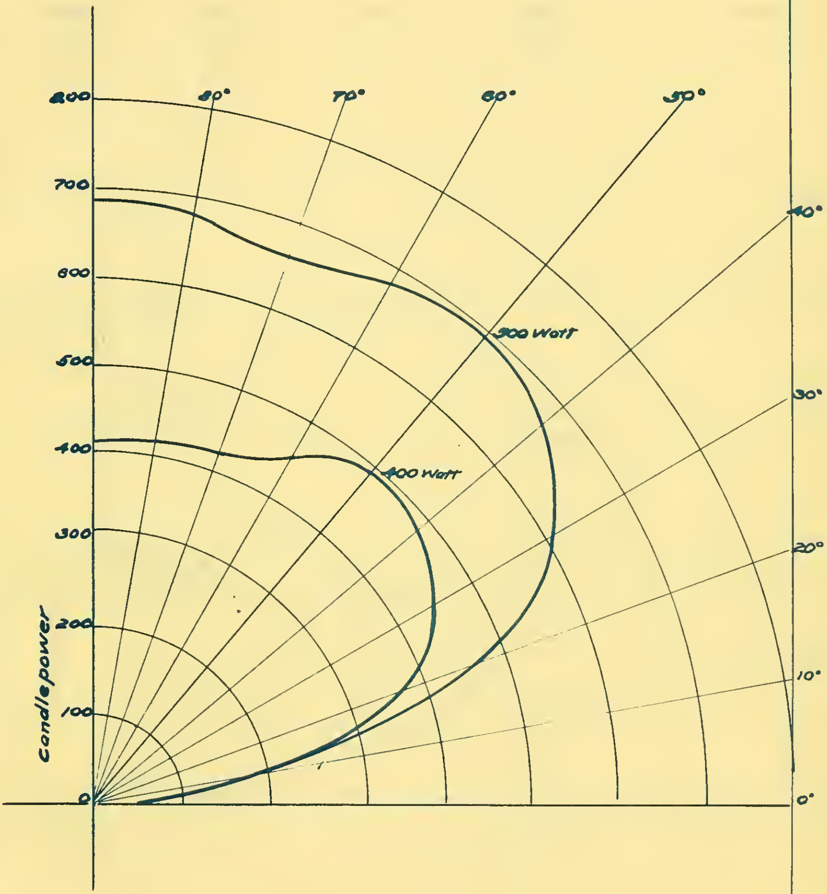
3. The average reading with #1 between mirrors, and headlight comparison lamp on photometer bar = 107.3 cm.



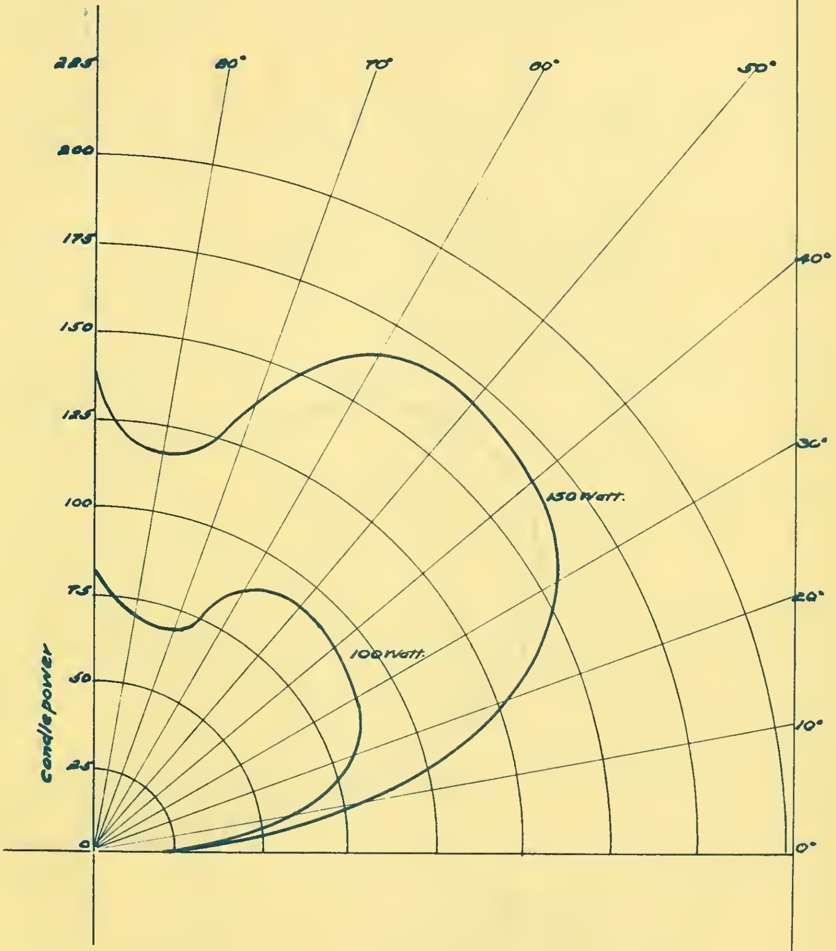
Distribution Curve
Carbon - Carbon Arc



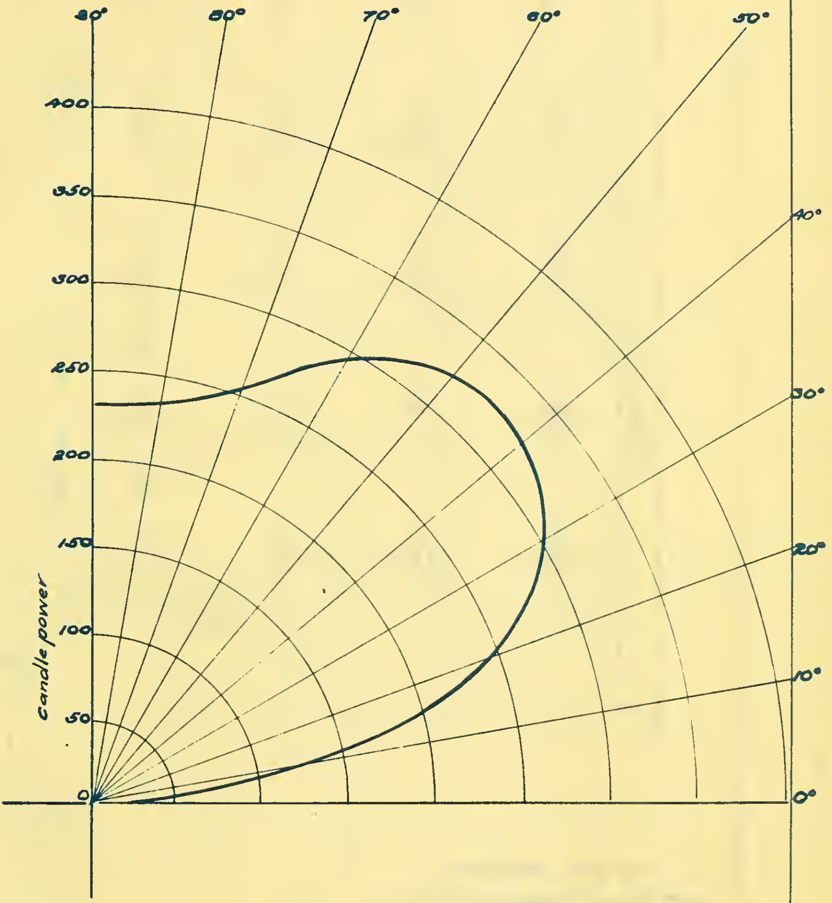
Distribution Curve
Carbon-Copper Arc



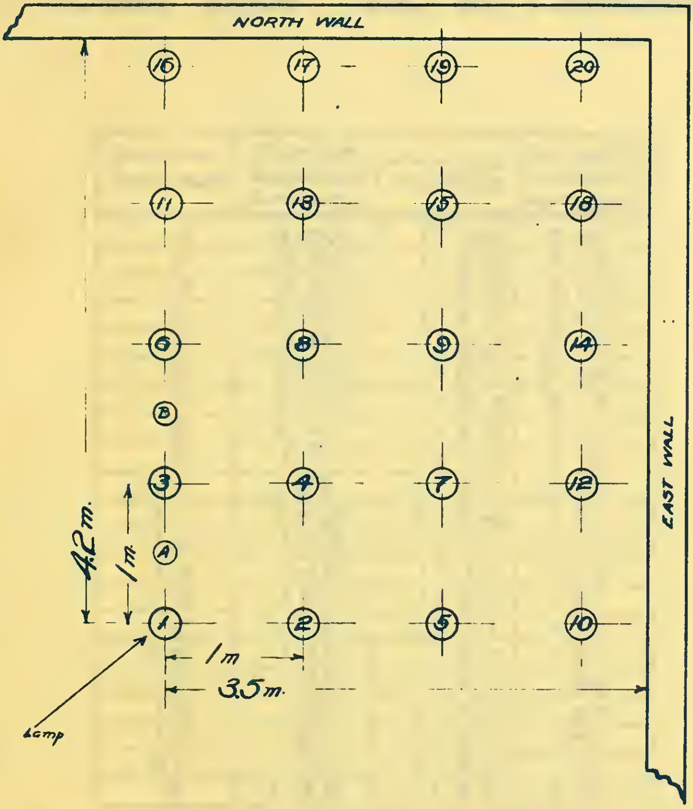
DISTRIBUTION CURVES
500 & 400
Watt Lamp
22" DIFFUSER



DISTRIBUTION CURVES
100 & 150
Watt Lamp
15" DIFFUSER.



DISTRIBUTION CURVES.
250
Watt Lamp
15" DIFFUSER



FLOOR PLAN
LECTURE ROOM
SURVEY STATIONS
SCALE 1" = 1 METER
DRAWN BY A.L.Arenberg '13
ARMOUR INSTITUTE OF TECHNOLOGY
5/15/13

HORIZONTAL SURVEY.

"500 watt" Lamp with 22" Reflector

Station Number.	Average Observed Intensity	Average Voltage.	Corrected Intensity. 112$^{v.}$ Basis.
1	3.54	113.0	3.41
2	3.30	113.2	3.16
3	3.36	113.6	3.17
4	2.85	111.7	2.89
5	2.48	112.5	2.44
6	2.38	112.5	2.34
7	2.15	112.0	2.15
8	2.20	112.8	2.15
9	1.71	111.2	1.79
10	1.69	113.1	1.62
11	1.59	113.4	1.51
12	1.56	113.0	1.50
13	1.43	113.0	1.38
14	1.25	113.0	1.21
15	1.19	113.1	1.15
16	1.03	112.0	1.03
17	.98	112.0	.98
18	.99	113.0	.95
19	.81	112.0	.81
20	.58	112.7	.57
A	3.48	113.3	3.32

Area of Room = 635 sq. ft. [58.8 sq. meters]

Average Intensity = 1.74 foot-Candles.

Effective flux = 1,105 lumens.

Lumens / watt, on working plane = 2.17

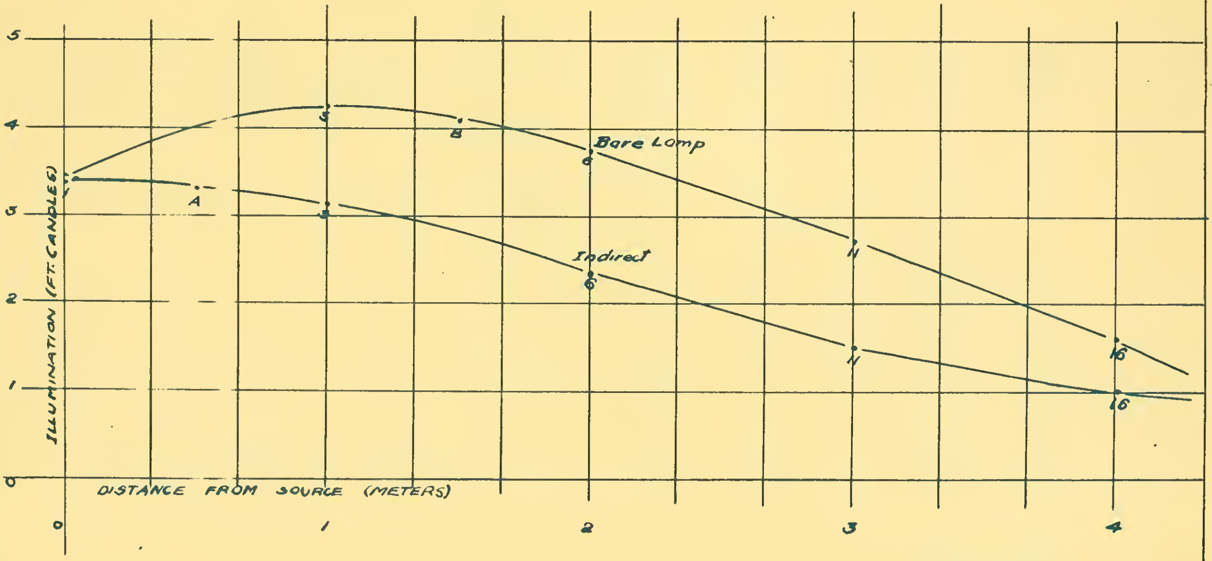
HORIZONTAL SURVEY.

"500 watt" bare Lamp

Station number.	Average Observed Intensity	Average Voltage.	Corrected Intensity. 112 v. Basis.
1	3.480	112.8	3.40
3	4.320	112.5	4.25
6	3.900	112.2	3.87
11	2.780	112.8	2.71
16	1.706	113.0	1.65
20	1.170	112.0	1.17
B	4.160	112.3	4.10

500 watt Lamp with 22" Reflector

Station number.	Height of Work. Plane	Intensity Foot. Candle
1	31"	3.41
3	31"	3.17
1	76'	7.70
3	76"	6.00
1	117"	15.00
3	117"	11.00



COMPARISON
BARE LAMP & INDIRECT SYSTEMS
"500 WATT" SPHERICAL MAZDA.
"ALEXALITE" DIFFUSER

A. S. Neuberg
R. E. Fischer